The Galactic System.[1]

By Dr. HARLOW SHAPLEY.

I.

THROUGHOUT the known sidereal universe there is, among material bodies, an obvious associative tendency, which we see well illustrated in meteor showers, in satellite and planetary systems, in binary stars, and in larger stellar groups such as the Pleiades. These various products of gravitational ordering are clearly but parts of still greater systems, and one of the most fascinating of astronomical studies is to attempt to seek out the structure of an all-inclusive sidereal organisation.

It is proposed in this communication to discuss the structure and extent of the sidereal system as indicated by recent studies of stellar clusters and variable stars. My own observational investigations of these objects, and the deductions based upon them, have been mainly published in Contributions and Communications of the Mount Wilson Observatory[1] from 1914 to 1918. The present discussion is made in the light of criticisms and numerous tests to which the conclusions have been subjected during the past four or five years.

It appears that we have three principal types of celestial objects to consider—the diffuse nebulæ, the stars, and the nebulæ of the spiral family. The first two are generally thought to be related as parent and offspring. The stars, having formed, as we think, out of nebulous pre-stellar states, are, apparently, largely organised into groups, a common, possibly prevailing form being the globular cluster. It is from combinations of these clusters that I believe our galactic system has developed.[2] From the work on clusters there can be little doubt of the enormous mass and dimensions of the galactic system as compared with clusters and nebulæ. Its flat form and heterogeneity, its content of numerous fragmentary systems (open clusters, wide binaries, spectrally-similar groups) of apparently different ages and separate origins, and its control over the motions of the clusters and near-by spirals, have led me for some years to advocate the hypothesis that the Galaxy is a growing composite of disintegrating minor systems. The Galaxy appears to include all the common sidereal types, with the probable exception of most nebulæ of the spiral family. But the latter are apparently not stellar in composition, nor galactic in size. I think present evidence favours but does not establish the hypothesis that typical spiral nebulæ represent a sidereal evolution not directly connected with that of stars.

The foregoing paragraph may serve as a brief outline. Some of the details may now be considered, but, before proceeding with the discussion, I should like to point out that the proposed interpretations involve the following somewhat fundamental assumptions, if we choose to call them assumptions: (1) that gravitation directs the organisation and motions of celestial bodies; (2) that the physical laws we know are equally valid in all parts of the space with which we are familiar; (3) that the Russell-Eddington theory of stellar evolution is correct in its general features.

Certainly these three are not serious restrictions. On the first I need make no comment here. The second is the basis of our belief in the general uniformity of conditions throughout the stellar system. It insists that our stellar neighbourhood is not operated by local laws. It is a highly reasonable but necessary assumption before we can safely compare the luminosities and other properties of stars near the sun with those of stars in distant parts of the galactic system. The third assumption, the Russell-Eddington theory, is not necessary for my conclusions concerning the dimensions of the galactic system, but is essential in putting together the general scheme, and also in trying to interpret some anomalies of the spiral nebulæ. We might call the evolutionary scheme the Lane-Lockyer - Ritter - Sampson - Emden - Schwarzschild - Hertzsprung - Russell - Eddington - Jeans - Eggert theory, but Russell and Eddington have been the most important contributors to the theory in its present form.

CONCERNING STAR CLUSTERS.

Clusters of stars can be placed in two fairly distinct categories, the globular cluster, of which nearly ninety are now known, and the open or loose cluster, of which there are several hundred.

Most globular clusters (but not quite all) appear to be remarkably alike in general structure. Compared with naked-eye objects they are extremely remote; hence their stars, though apparently very faint, are actually of high intrinsic luminosity. Few stars in globular clusters are brighter than the eleventh apparent magnitude. Each globular cluster contains some tens of thousands of these intrinsically bright stars, and possibly a far greater number of dwarfs, which at present are beyond the reach of our telescopes. Of high importance is the fact that the cluster stars appear to be remarkably similar to the stars in the solar neighbourhood in spectral type, colour, variability, and other properties, notwithstanding the much higher stellar density near the centres of globular clusters.

Open clusters are of great variety. They range in brightness from naked-eye systems, such as the Hyades, to small, dim groupings that may be nothing more than chance aggregations of faint Milky Way stars. Open clusters vary also in richness, in apparent and real dimensions, in stellar content. One property they have in common: they are all near the plane of the Milky Way. The distance of the average open cluster is smaller than that of globular clusters, but the determination of distances for the former is generally subject to much uncertainty. This fact is due to variety of form and content, and to the absence from open clusters of peculiar types of highly luminous stars, which for globular clusters serve to determine positions in space.

The estimation of the distances of globular clusters, which has been the most important part of the work on the scale of the sidereal universe, must be based on the newer methods of measuring space. The various trigonometrical methods, when applied to globular clusters, so far give negative results, indicating only that the distances are very great. The various photometric methods that had to be developed for this problem involve a considerable amount of photometric, spectroscopic, and statistical detail when put on a quantitative basis, and cannot be fully described in this article.

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[1] Adapted from an Address given before the British Astronomical Association on May 31.

The qualitative application of the photometric methods, however, is simple. For example, we need only assume that the brightest stars in a globular cluster have the same actual luminosity as the brightest stars in the solar neighbourhood, and we can readily compute the distance necessary to give them the apparent brightness that is measured.

If we admit the similarity of globular clusters, it is obvious that either the apparent magnitude or the apparent diameter can give us the distances of them all when once we have determined the distances of those nearer the earth. In practice the distances of the nearest clusters have been determined from studies of their variable stars, of their blue stars (spectral type B), and of their red giant stars; and checked by spectroscopically-determined absolute magnitudes and by means of the relative diameters. All the methods agree in giving distances of the same order of magnitude. We thus find that the globular clusters range in distance from seven thousand parsecs to values nearly ten times as great. Their diameters are of the order of a hundred parsecs. Their brightest stars are a thousand times as bright as the sun.

THE STRUCTURE OF THE GALAXY.

The result of most interest that comes out of this photometric investigation is the enormous dimensions of the super-system of globular clusters and of the Galaxy. Once the positions in space are determined, it becomes clear, as had already been suspected from an inspection of the apparent distribution of clusters in the sky, that globular clusters are a part of the Milky Way system. They are associated physically with the system of stars, nebulæ, and open clusters which is more or less symmetrically arranged with respect to the equatorial plane of the Galaxy. In measuring the distances of the remotest globular clusters, therefore, we are but measuring the depth of our own galactic system. That the Milky Way itself extends to distances as great as those indicated by the clusters is shown by the presence within it of highly luminous types of stars with apparent magnitude 15 and fainter.

It has been known for many years that globular clusters are not uniformly distributed in galactic longitude. They are most numerous along the edges of the southern Milky Way. That one-sided distribution is now recognised as an indication of the sun's very eccentric position in the galactic system. In this same southern part of the sky we find the densest galactic star-clouds and the greatest frequency of faint novæ and of other types of distant objects, which is but further evidence of the greater depth of the galactic system in the direction of Sagittarius. Also in that general direction are some obstructing dark nebulæ, which may be wholly responsible for a peculiar phenomenon in the distribution of distant globular clusters, that is, in their seeming absence from regions very close to the galactic plane. If the obstructing material were removed, we might see, near the galactic plane, clouds of faint Milky Way stars still more dazzling than those observed, and globular clusters still more distant than those now known, and hence find that the greatest diameter of the galactic system is even larger than the value now assigned—approximately 100,000 parsecs.

The observable dynamical relations within and without the Milky Way are suggestive of its origin. No open clusters have yet been found outside the Milky Way region, but hundreds are known within. North and south of the galactic plane the globular clusters are equal in number, and their distances from the plane are much smaller than the greatest diameter of the system. Their velocities, so far as now known, are high. Many are approaching the galactic plane with speeds that soon must bring them to it. Their present positions and motions make orbital motion around the Milky Way improbable. From the present evidence as to mass, velocity, and distribution, there can be little doubt but that the known globular clusters pass to and fro through the star fields of the galactic system, notwithstanding their observed avoidance, apparent or temporary, at the present time. Every passage must reduce the velocity and alter the form. The hypothesis that these globular clusters are being diverted by degrees into galactic regions, and gradually robbed of their stars, is upheld by observation and is not opposed by present dynamical theory. Although we see few intermediates between the globular and the more typical open clusters, many of the characteristics of the open groups strongly support the suggestion that they are the remnants of globular clusters or of other systems that have been assimilated by the incomparably more massive galactic assemblage. Nearly a dozen "moving" clusters, comprising thousands of members, are recognised among the stars within seven hundred light-years of the sun.

Two important theoretical researches by Jeans are of much significance in this view of galactic structure: (i.) the form resulting from the interpenetration of two clusters,[3] and (ii.) the necessity, in accounting for the present orbits of long-period binaries, of assuming their former existence in a much more compact stellar field than now exists in the solar neighbourhood.[4] The high stellar frequency near the centre of a globular cluster would certainly supply conditions favourable for modifying orbits, and it also might aid in explaining the origin of long-period binaries which is not otherwise accounted for satisfactorily.

The determination, with the aid of clusters, of dimensions for the galactic system much larger than had been clearly indicated by studies of the nearer galactic stars, led to a further examination of the stellar distribution in the solar neighbourhood. The hypothesis that the galactic system, as we now know it, has developed from the combination of minor groups, suggests that the brighter stars near the sun may to a large extent be members of a local system that is imbedded in and moving through the general star fields of the Milky Way. This condition actually appears to be the case, and hence the results on galactic dimensions, from clusters and from the nearer stars, do not contradict. Stars of spectral type B down to the sixth apparent magnitude seem to be almost exclusively members of a local cluster or cloud. Brighter stars of Class A are also affiliated with the same system.[5] Probably all the other types are to some extent involved,[6] but for them the disentanglement of local system and galactic field is more difficult.

Quite analogous to the phenomenon of the Milky Way, the projection on the sky of the faint stars along the central plane of this local cloud gives rise to a sort of secondary Galaxy,[7] the brighter stars of which coincide roughly with the Herschel-Gould belt. The distribution of the B stars indicates that the dimensions of the local system are large compared with those of a globular cluster; the local system is also more oblate. I believe it can be better compared in dimensions, and possibly in form, with the Magellanic Clouds or with the distinctly delimited small star clouds of the Milky Way. The various phenomena of star streaming are undoubtedly connected with the motions of and within the local system. Probably a number of our brighter "moving" clusters should be considered sub-systems in the local cloud, rather than independent systems which for the time being are near at hand.

(*To be continued.*)

REFERENCES.

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Transport of Organic Substances in Plants.[1]

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AMONG physiologists the usually accepted view is that organic substances are distributed throughout the plant by means of the bast. The wood also acts as a channel of distribution for these substances to opening buds and developing leaves, especially in spring when root-pressure is active. The sap of bleeding contains appreciable quantities of these substances, and their distribution to the developing buds in spring by means of the wood was recognised by Hartig and Sachs.

This upward transport of carbohydrates in the tracheæ seems to be accompanied with smaller amounts of proteins. Thus Schroeder showed that the quantity of proteins in the bleeding sap rises and falls with the quantity of sugar.

This view that the rising current in the tracheæ carries organic substances in it and distributes them to the growing regions has lately been impugned. It was pointed out that in many cases, ringing close below the terminal bud prevents the development of that bud because the wood is unable to transmit sufficient supplies of organic substance. As Strasburger has already shown, this interpretation rests upon the fallacy of supposing that the removal of the bark as far as the cambium leaves the wood uninjured. As a matter of fact, microscopic examination of the wood, from which the outer tissues have been stripped, shows that its tracheæ soon become blocked with air-bubbles and with substances probably exuded into them and their walls during morbid changes in the cells of the cambium, in the cells of the medullary rays, and in those of the wood-parenchyma. The blocking is accompanied with discoloration, and is most apparent in the outer layers of the wood. It is only reasonable to suppose that the efficiency of the tracheæ as channels of transmission is seriously impaired even before there is visible evidence of plugging.

It is evident that this clogging may act differentially on the water and the substances carried in it. In the first place, the whole cross-section of the wood is available for the transport of water, while probably the outer layers are mainly utilised by the organic substances. Further, colloidal deposits in the walls, and especially in the pit-membranes, would obstruct the passage of organic substances much more than they would the water which carries them. These considerations readily explain how it is that, while the water-supply to the buds of ringed branches is adequate, the supply of organic substance may be deficient.

Apart, then, from the very slow movement of organic substances from cell to cell, there is very cogent evidence that their upward motion is effected in the tracheæ of the wood. There is no reason to believe that during this transport the walls or pit-membranes of these tracheæ oppose the passage of the dissolved carbohydrates or of the simpler proteins any more than the water which conveys them. Hence the velocity of transport of these organic substances is that of the transpiration current, and the amount conveyed in a given time depends on the velocity and concentration of the stream.

The transport of organic substances in an upward direction in plants is secondary, for, as is well known, carbohydrates certainly, and proteins most probably, are manufactured only in the upper green parts of plants—principally in the leaves, and must be transported in the first instance back from these to the stems to be distributed to the growing regions and to the storage organs.

This view that the channel for the backward and downward movement of organic substances is afforded by the bast received great support from Czapek's work published in 1897. By section of the conducting tracts in one half of the petiole he showed that depletion of the corresponding half of the blade was delayed. He also showed that only where vertical bridges connected the upper and lower portions of bark in ringed stems were the effects of ringing nullified. Oblique and zigzag bridges are ineffective. Thus transverse conveyance in the stem is negligible. The parallel and longitudinal arrangement of the elongated elements in the bast seemed to him to provide adequately for the observed longitudinal passage. Their narrowness and large colloid content did not present themselves as difficulties. Czapek also recorded the observation that the blades of leaves, the petioles of which had been killed by jacketing them with steam, did not become emptied of starch. Similarly, when the petioles were killed with chloroform-vapour, depletion was arrested. Again, anæsthetisation of the petiole, by surrounding

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[1] From the presidential address delivered to Section K (Botany) of the British Association at Hull on Sept. 7.